Passive A-Band Wind Sounder (PAWS) For Measuring Tropospheric Wind Velocity

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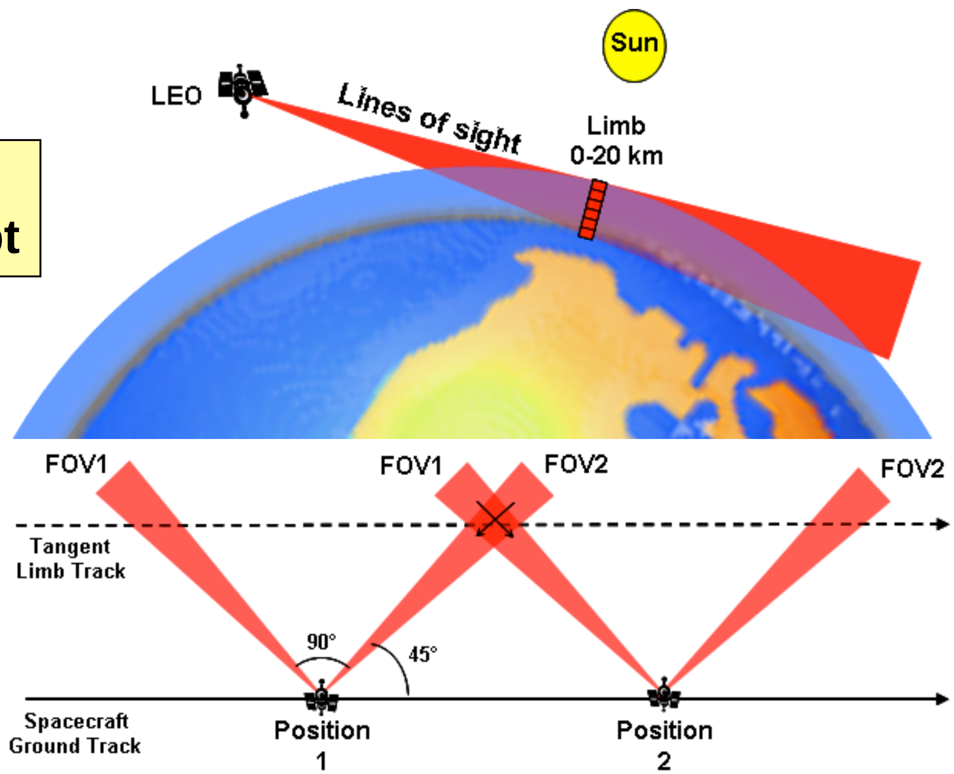
Ball Aerospace
& Technologies Corp.

Agility to innovate,
Strength to deliver

PAWS Overview

- Instrument Incubator Program (2004)
- Objectives
  - Demonstrate an instrument concept for passive measurement of tropospheric wind speed using Doppler shifts in oxygen absorption features
- Motivation
  - Improve global coverage of wind measurements
  - Improve weather forecasting
    - "number one unmet measurement objective for improving weather forecasts" NRC Decadal Survey

On-Orbit Viewing Concept



Heritage for PAWS

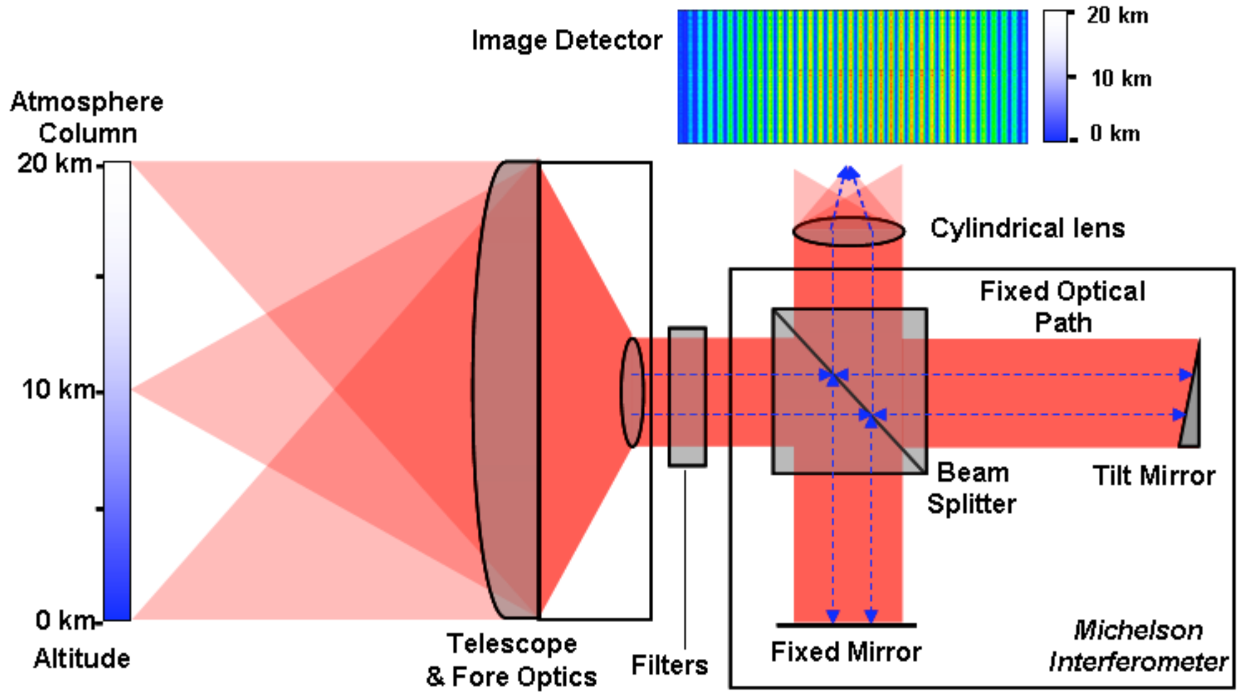
	WINDII	HRDI	PAWS
Vertical Coverage	80 – 300 km	10 – 115 km	0 – 20 km
Vertical Interval	2 km	2.5 km	1 km
Horiz. Cell Size	140 km	500 km	250 km
Spectral Signal	Emission	Absorption	Absorption
Target Species	O and OH	O_2 B and γ Bands	O_2 A-Band
Spectrometer	Imaging Michelson, fixed FOV	Triple Fabry-Perot	Imaging Michelson, fixed FOV
Meas. Approach	Large OPD, scan across one period	Gimbal telescope Angle/gap scan	Large OPD, fixed tilted mirror
Accuracy	~ 5 m/s	~ 3 to 12 m/s	~ 5 m/s (TBD)

Upper Atmosphere Research Satellite

- Wind Imaging Interferometer (WINDII) — Sep 1991 to Dec 2005
- High-Resolution Doppler Imager (HRDI) — Sep 1991 to ~2000

PAWS Instrument Approach

Simple components with flight heritage

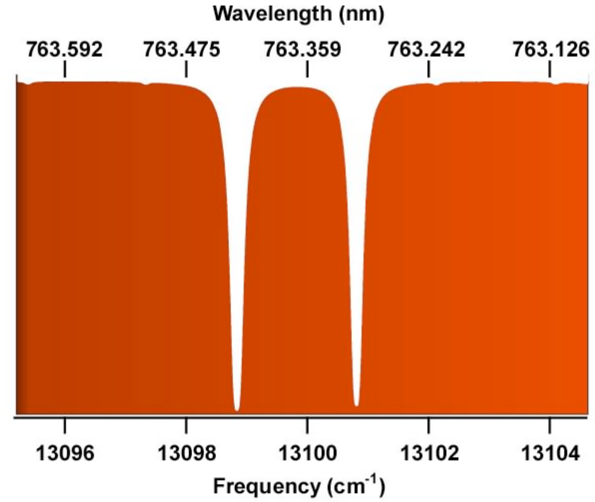


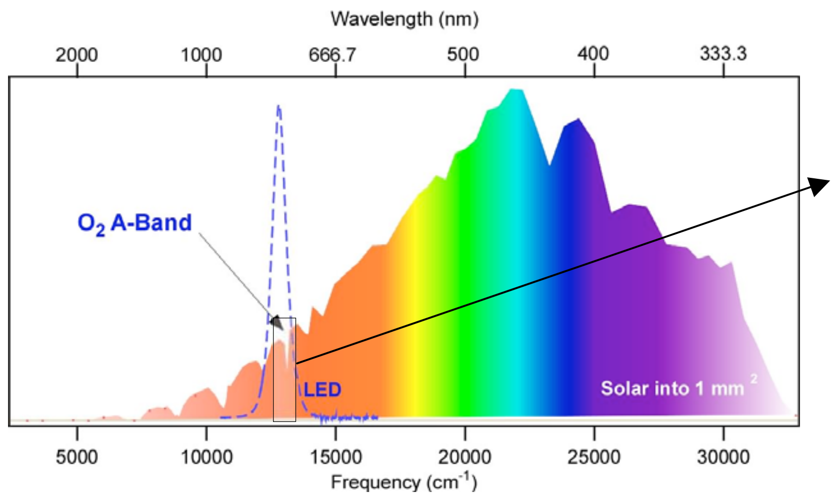
- Limitations of the Technique
  - Daytime-only measurements
  - Will not provide the accuracy, precision, or spatial resolution anticipated for Doppler lidar
- Potential Advantages of the Technique
  - Simple components with proven space heritage
  - Low cost, risk, and platform requirements, and insensitive to spacecraft altitude
  - Much better wind data than is currently available

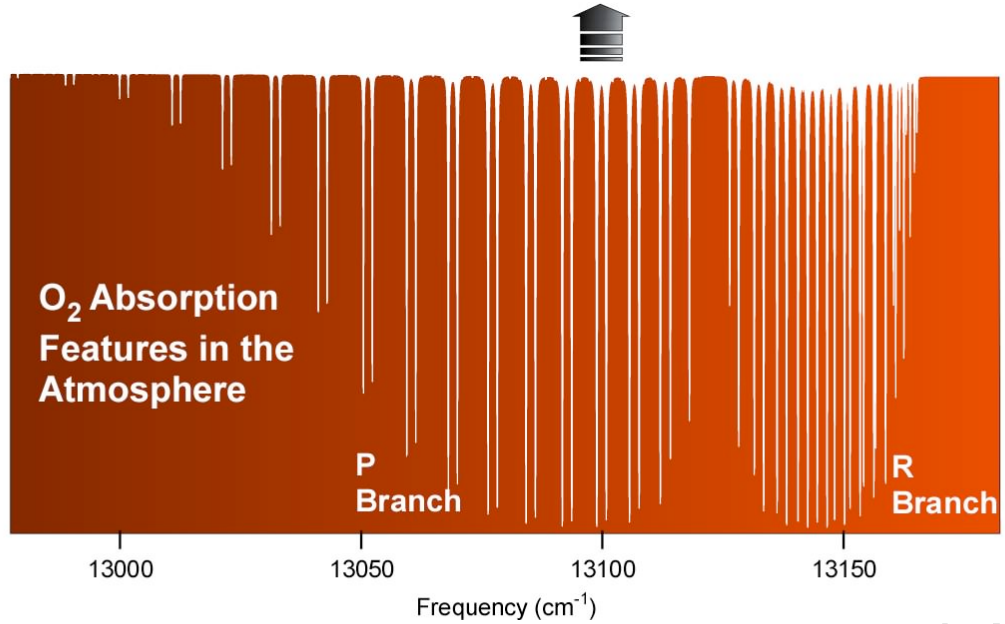
Measurement Approach

Oxygen A-Band Transmission & Line Selection

- Lines are in a clear region of the atmospheric absorption spectrum
- Lines are extremely sharp and well resolved
- Wide range of line strength is available to optimize SNR
- Oxygen is an excellent tracer molecule for the troposphere
- A-band wavelength region is compatible with technology for high spectral resolution

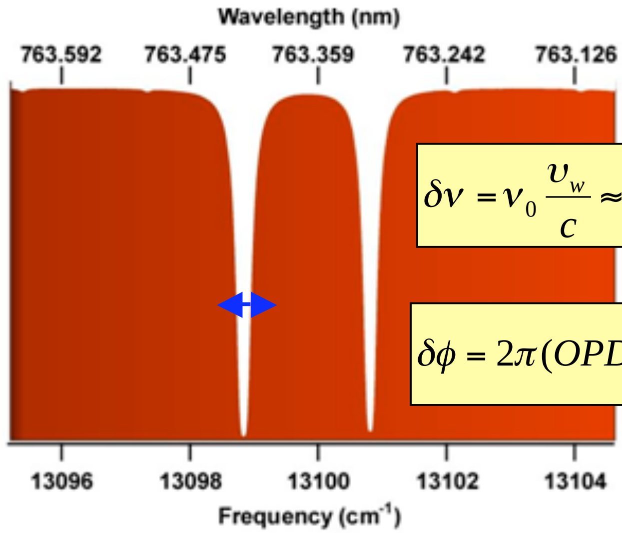






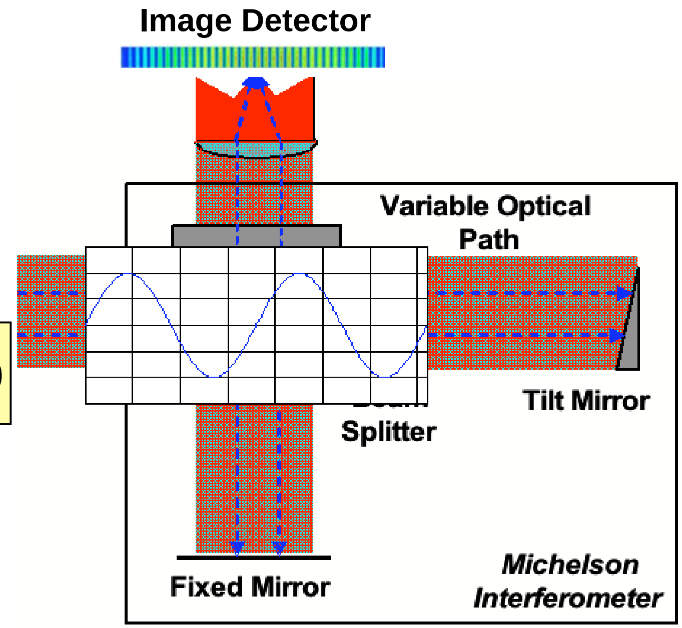
Measurement Approach

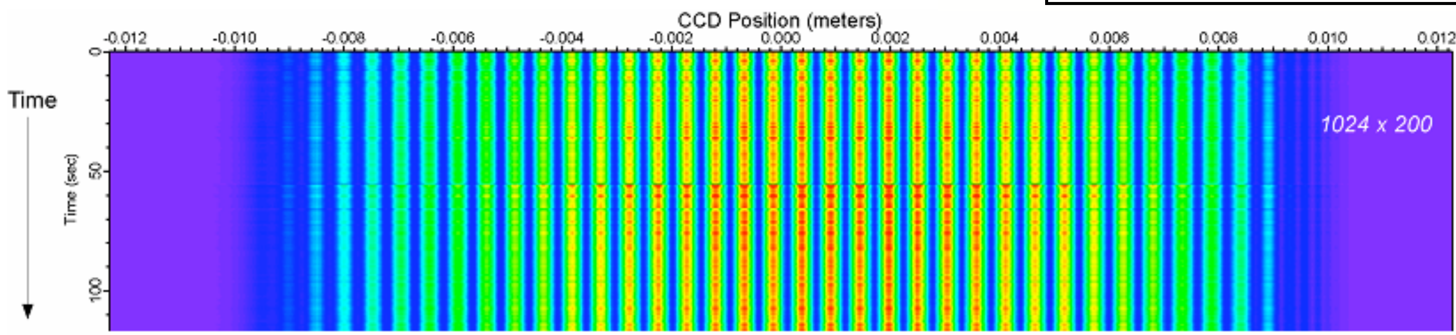
Detecting Doppler Shift with a Michelson Interferometer

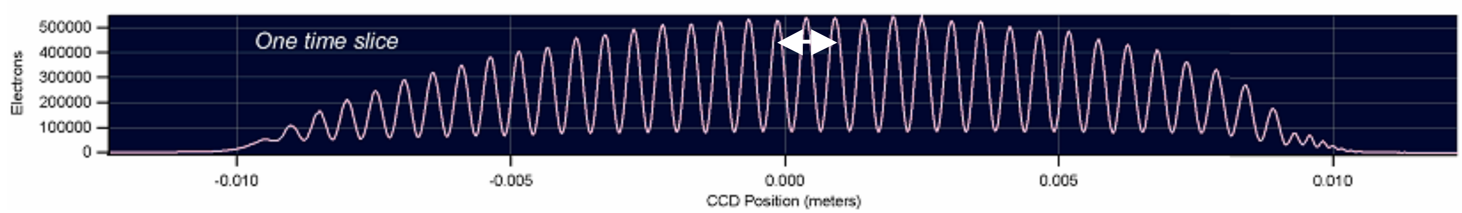


$$\delta\nu = \nu_0 \frac{\upsilon_w}{c} \approx 10\text{s of } fm$$

$$\delta\phi = 2\pi(OPD)\nu_0 \frac{\upsilon_w}{c} + F(OPD)$$

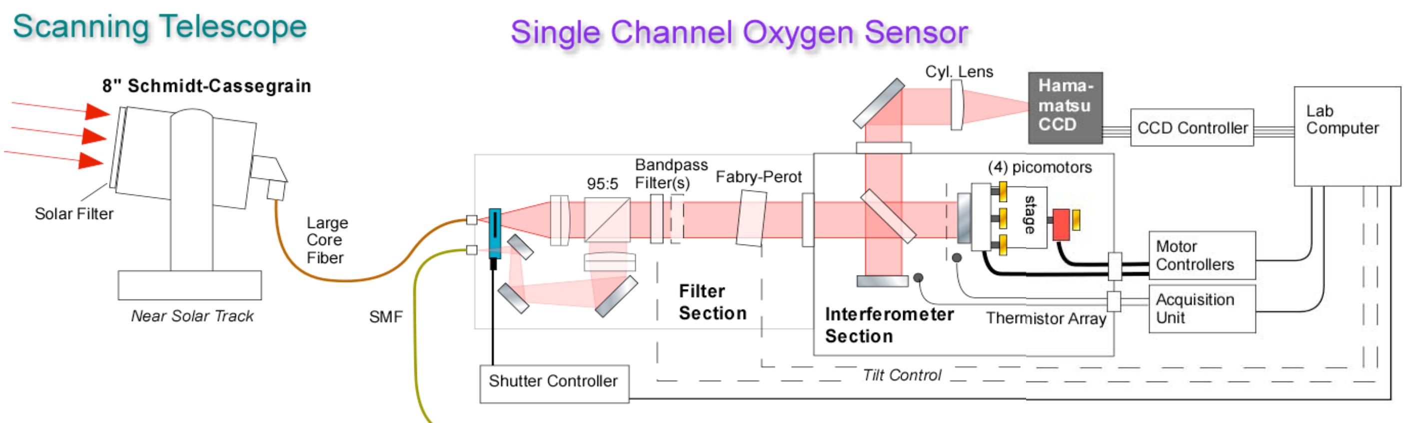


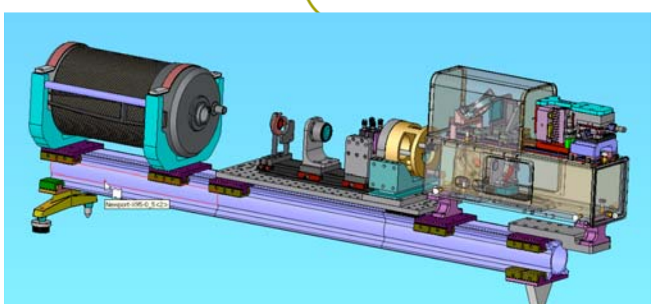


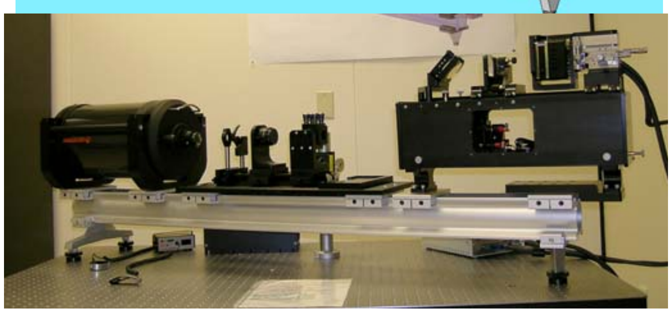


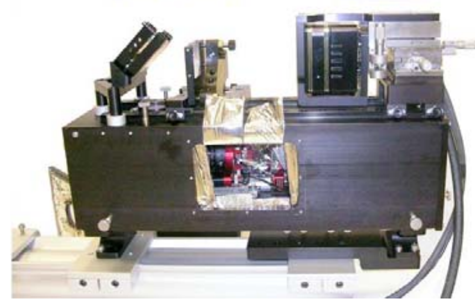
Years 1 and 2: PAWS Breadboard and Analysis

Path-finding tool – sacrifices stability for versatility



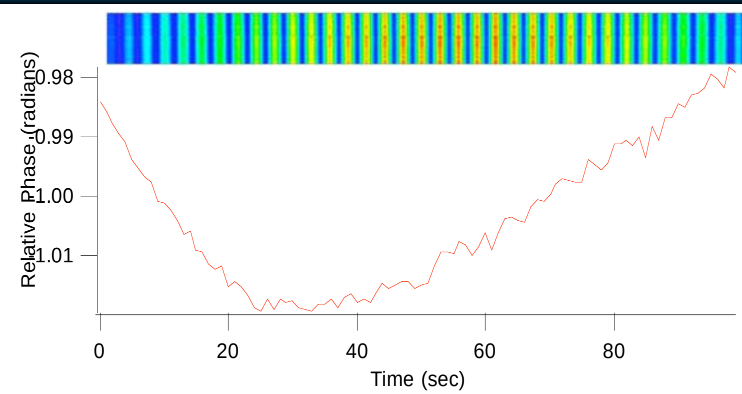






Years 1 and 2: Lessons Learned

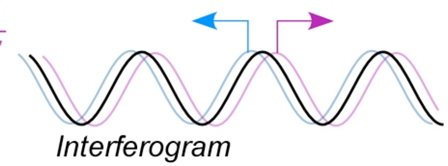
- Breadboard very sensitive
  - Need to improve stability by 100x
  - Wind speed error ± 20 m/sec
- Require extremely rigid construction
- Combining air-spaced etalon and Michelson reduces sensitivity to pressure and temperature
- Temperature and pressure stability
  - 0.07 K and 0.7 Torr = 0.5 m/sec EDS
- Spatially homogeneous light sources
- Using an absorption doublet doubles the SNR
- The shot noise limited wind speed detection is about 0.1 m/sec
- Optical path difference of 1.5 cm with one etalon (baseline)
- Demo and calibration requires wind tunnel and deep absorption

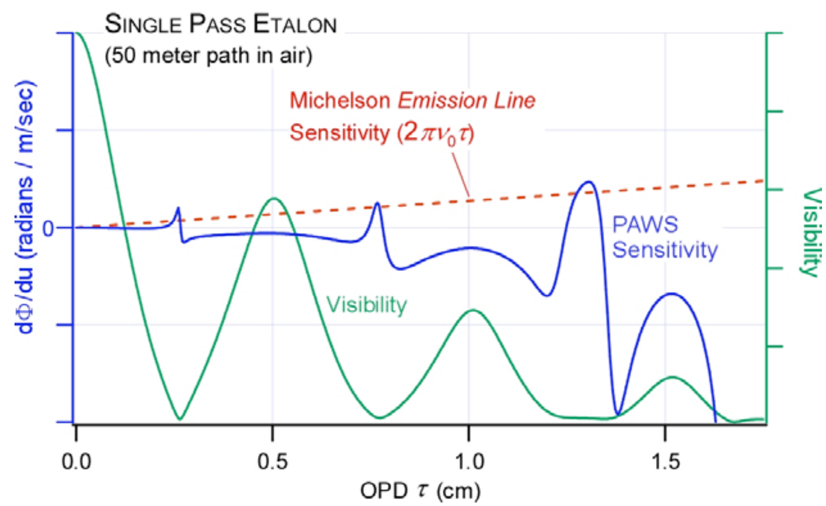


ETALON MICHELSON

$$\frac{1}{\nu_0}\frac{d\nu_0}{dT} \approx -\frac{1}{\tau}\frac{d\tau}{dT}$$

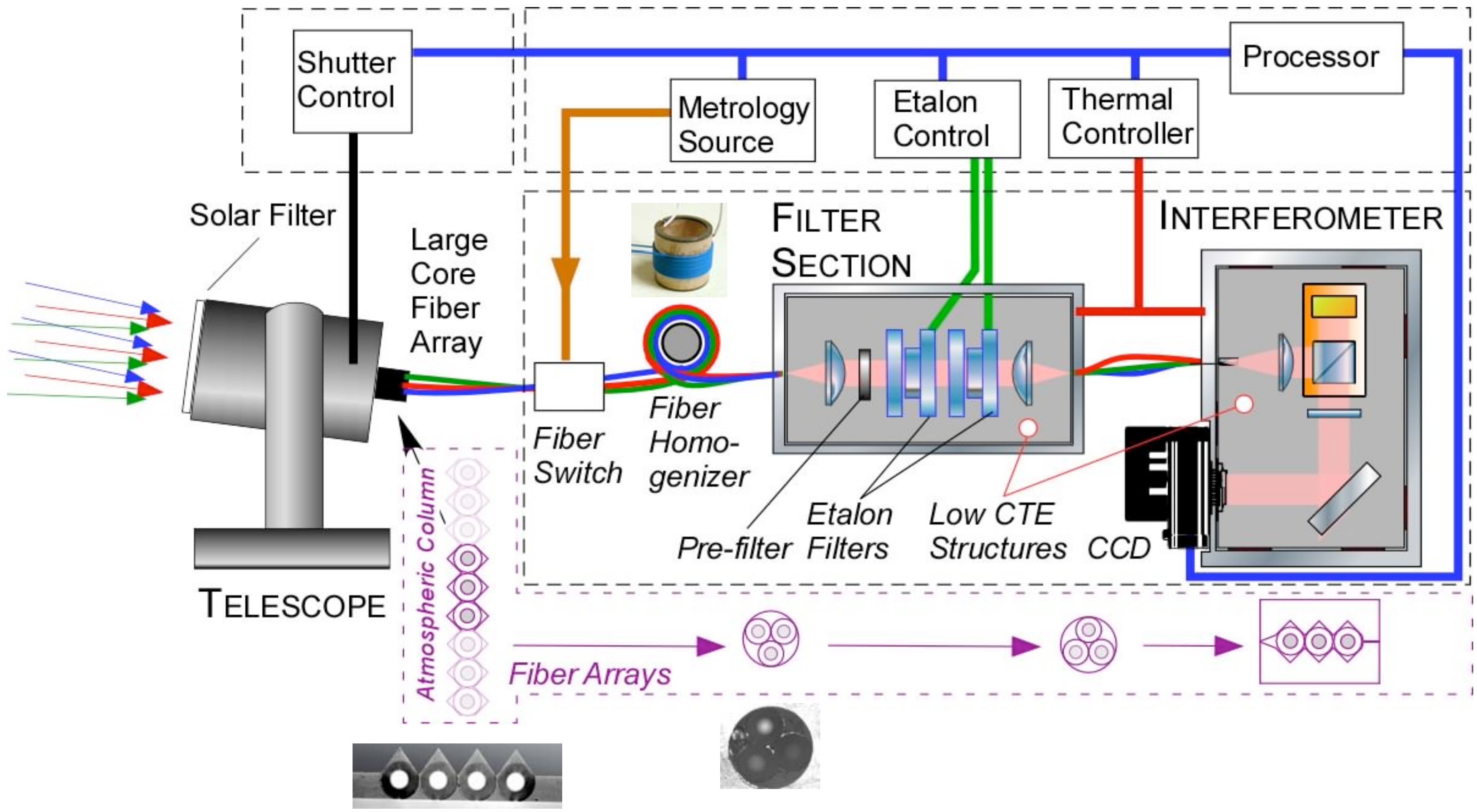
$$\frac{1}{\nu_0}\frac{d\nu_0}{dP} \approx -\frac{1}{\tau}\frac{d\tau}{dP}$$





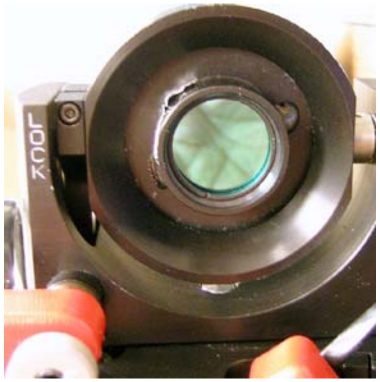
Engineering Unit Diagram

- Modular, Fiber-Coupled Design
- Emphasizes Stability
- Three Vertical Elements in FOV



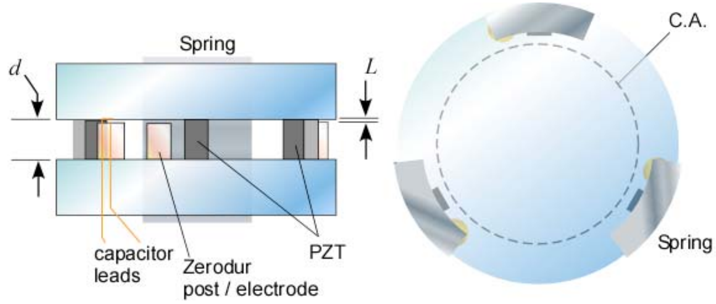
Engineering Unit Filtering Approach

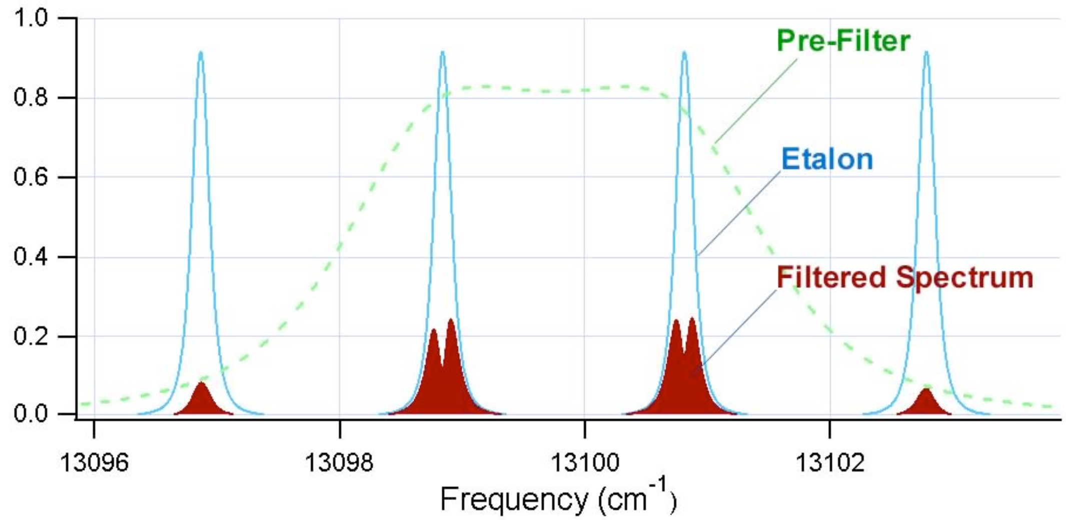
- Pre-Filter (0.22 nm FWHM)



- Stability is critical
  - Fixed-spacing ideal for flight, but too expensive for IIP to achieve nm spacing tolerance
- Tuning is required for EU
  - Angle tuning is not desirable due to field dependence of filter function
  - Pressure tuning is complicated and less compatible with space platform
  - PZT tuning allows normal incidence and high sensitivity

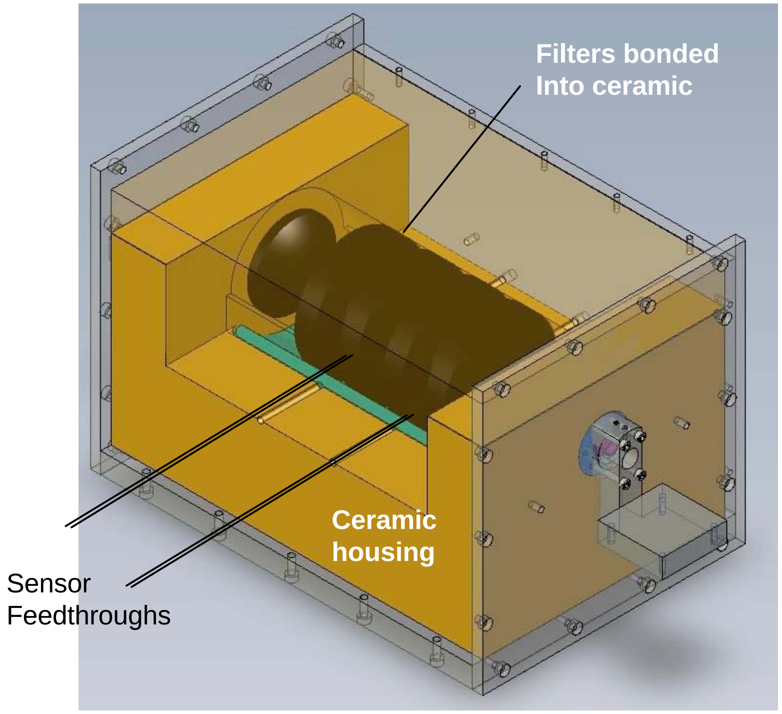
- Filter: Air-Spaced Etalon
  - Centered near 13100 cm^{-1} (763.35 nm)
  - Modest finesse requirement



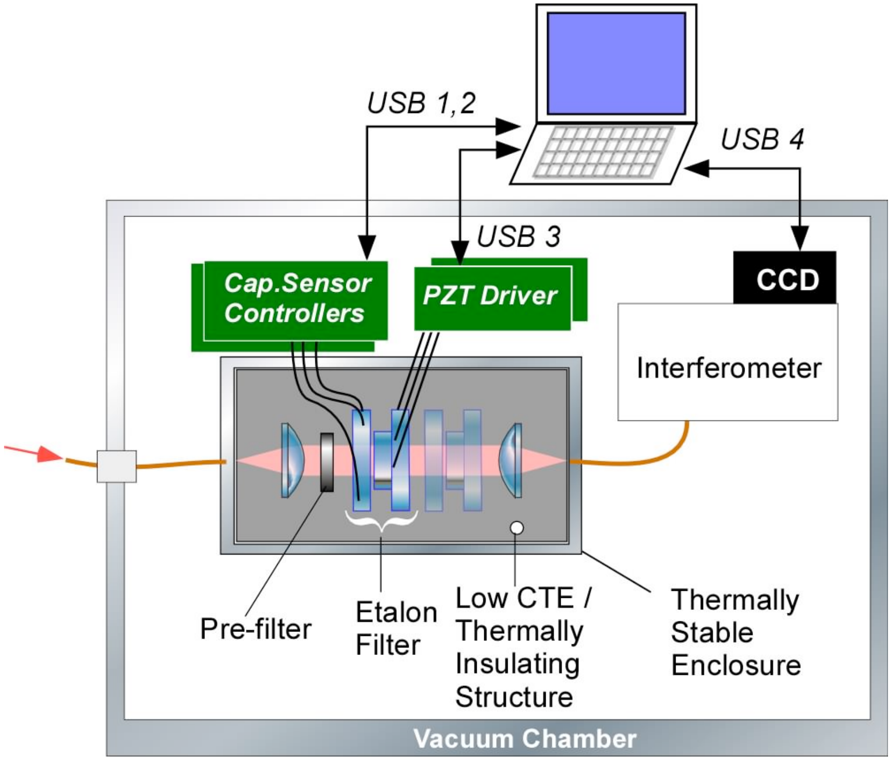


Engineering Unit Filter Section

- Modular Filter Section
  - Simplifies design; Improves versatility
- External aluminum housing (± 0.7K)
- Internal ceramic housing
  - Low CTE & thermal conductivity; stiff
- Etalon(s) bonded to ceramic (± 0.07K)

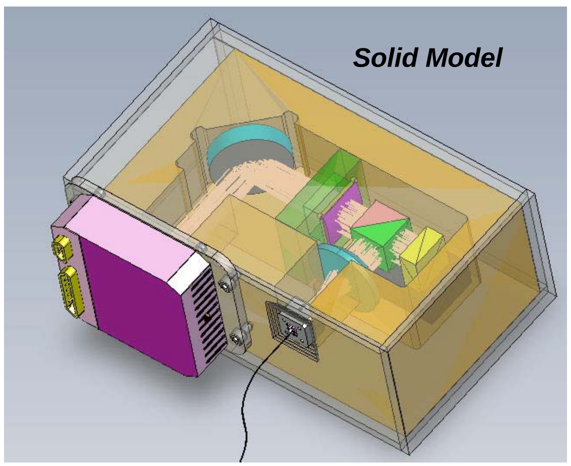


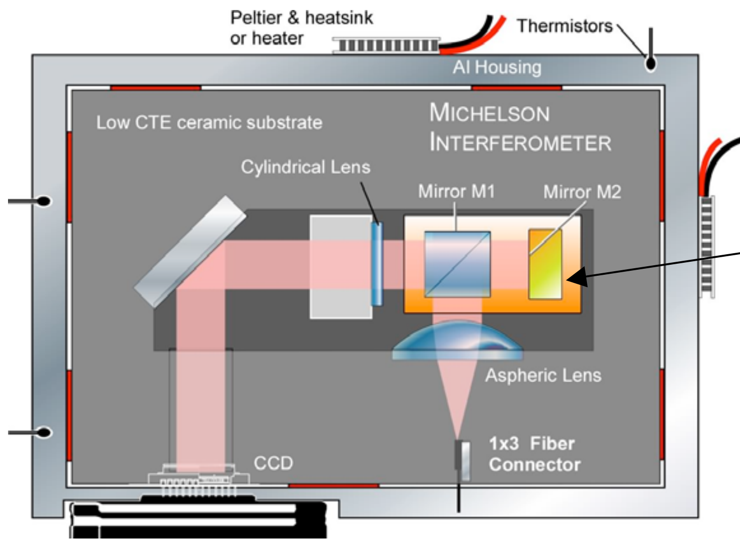
- Etalon Tuning
  - Maximize metrology signal on CCD
  - CCD readout to PZT driver to tune etalon
- Etalon Stabilization
  - Capacitance sensor to PZT to hold capacitance

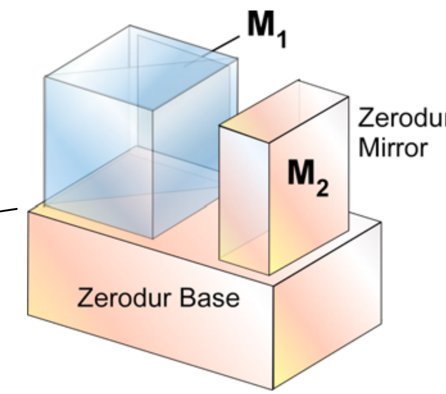


Engineering Unit Interferometer Section

- External aluminum housing (± 0.7K)
- Internal ceramic housing
  - Low CTE & thermal conductivity; stiff
- Components bonded to ceramic housing
- Cube beam splitter and Zerodur mirror
- Hydroxide catalysis bonded to Zerodur base
- Temperature controlled to ± 0.07K

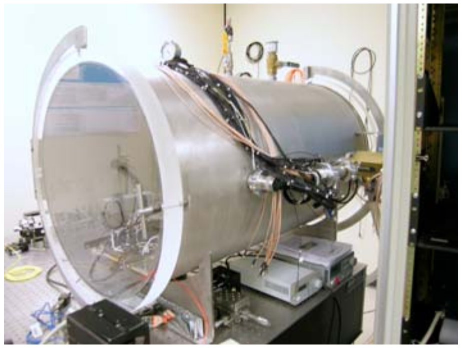


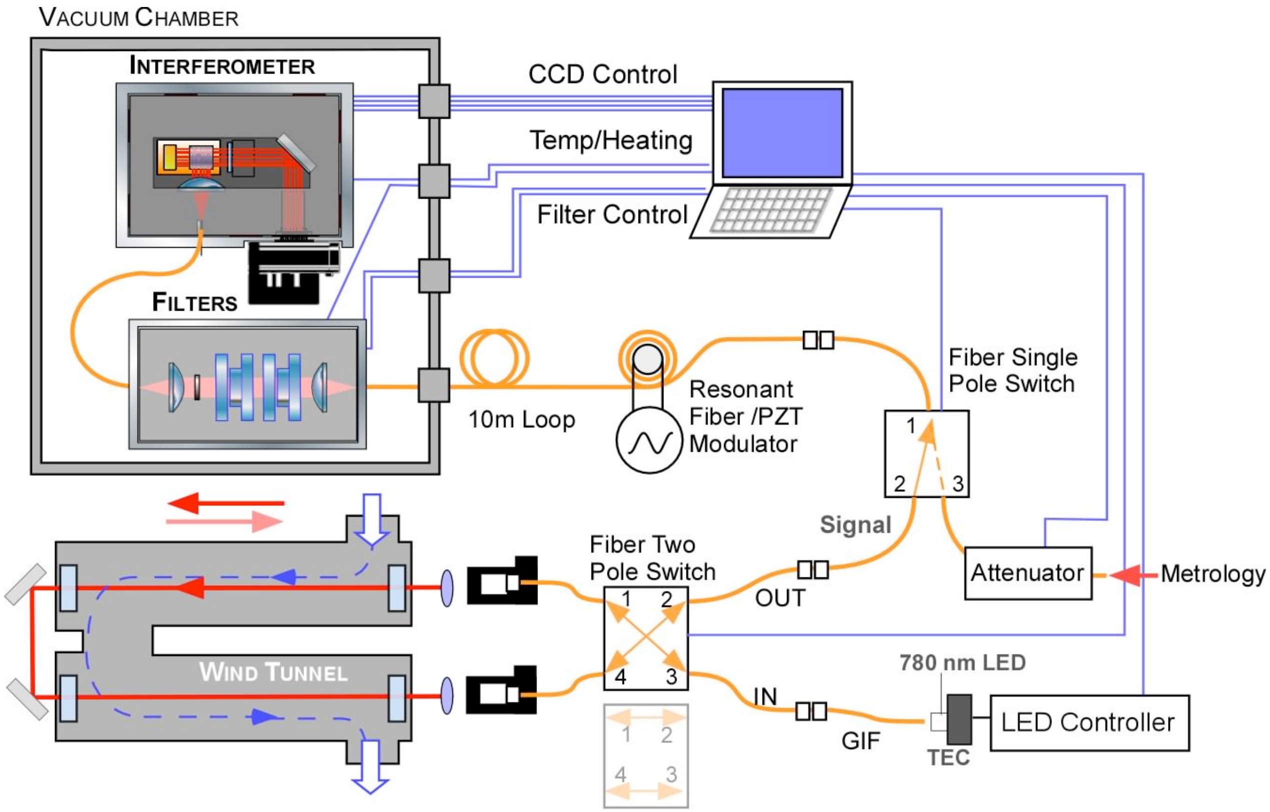




Engineering Unit Laboratory Testing

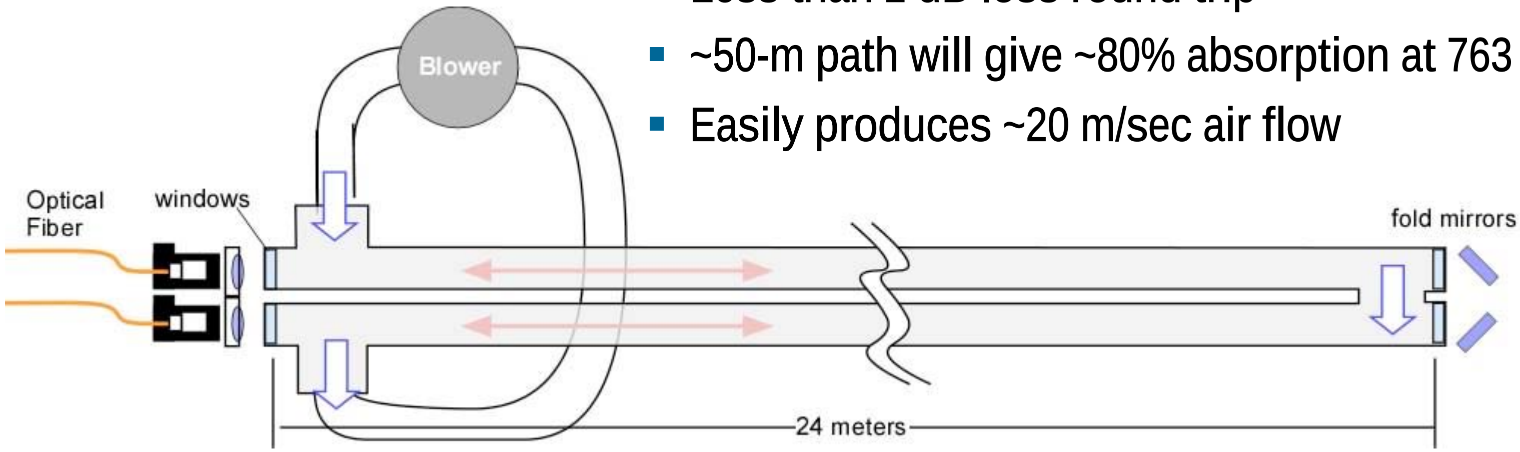
- Instrument sealed in pressure-stabilized chamber
- LED source provides artificial sunlight
- Telecom fiber optic switches provide differential wind measurement and metrology source injection





Wind Tunnel for Laboratory Testing

- Less than 2 dB loss round trip
- ~50-m path will give ~80% absorption at 763 nm
- Easily produces ~20 m/sec air flow



Summary and Conclusions

- PAWS targets the troposphere, so absorption lines are used rather than emission
  - Narrow absorption lines buried in a relatively broad background signal
  - Complicates the sensitivity of the measurement
  - Imposes tough requirements on system stability
- Engineering unit approach
  - Air-spaced etalon and Michelson interferometer
  - Fiber coupled, modular design
  - Rigid, low thermal expansion housing
  - Measure two absorption lines: doubles SNR
  - Minimize temperature and pressure fluctuations
  - Engineering unit will be capable of measuring wind at 5 m/s with the wind tunnel
- Path to Flight
  - Fixed-space etalons (is tuning required?)
  - Two or more filter modules of optimal performance over 20-km limb
  - A-band emission lamp for on-board calibration
  - Couple with A-band spectrometer for peak shape (pressure, cloud height)